



# The Ecosystem Functions Model: A Tool for Restoration Planning

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**PURPOSE:** The Ecosystem Functions Model (EFM) is a planning tool that analyzes ecosystem response to changes in flow regime. The U.S. Army Corps of Engineers' Hydrologic Engineering Center (HEC) is developing the EFM and envisions environmental planners, biologists, and engineers using the model to help determine whether proposed alternatives (e.g., reservoir operations or levee alignments) would maintain, enhance, or diminish ecosystem health. Project teams can use the EFM to visualize existing ecologic conditions, highlight promising restoration sites, and assess and rank alternatives according to the relative enhancement (or decline) of ecosystem aspects. This software is a general tool, applicable to a wide range of ecotypes and Corps projects.

**BACKGROUND:** The EFM was developed as part of the Sacramento and San Joaquin River Basins Comprehensive Study (Comprehensive Study). The Comprehensive Study, authorized by Congress in 1998, partners the U.S. Army Corps of Engineers (USACE) and the Reclamation Board of California in an effort to explore flood damage reduction and ecosystem restoration opportunities in the Central Valley, California.

Conceptually, the EFM was formulated as a diverse list of interrelated ecosystem elements of concern to Comprehensive Study restoration efforts. However, at that time, no detail was attached to how these elements would be investigated spatially, temporally, or quantitatively. As development progressed, questions were raised regarding the actual workings of the EFM. Focus began to be placed on model construct and how it would be used to assess the ecosystem elements highlighted during conceptual development. The Study Team, California Department of Water Resources, HEC, and Jones and Stokes cooperatively developed the first quantitative version of the EFM, which used statistical analyses as indicators of ecosystem elements.

HEC continued EFM development and constructed a model interface that allows users to:  
1) specify and perform statistical analyses designed to provide insight to ecosystem dynamics and response to changes in flow regime, and 2) use GIS software to support restoration planning.

## MODEL DESCRIPTION

**Overview.** EFM analyses typically involve: 1) statistical analyses of relationships between hydrology, hydraulics, and ecology, 2) hydraulic modeling, and 3) GIS programs to display results and other relevant spatial data. The EFM is a computer model that consists of a user interface and an ArcGIS extension. The hydraulic modeling portion of the EFM process is performed by existing independent software such as HEC's River Analysis System (HEC-RAS).

**Data Streams.** Data requirements of the EFM are related to the level of detail desired by the modeler. If only statistical results are desired, then required data consist only of flow and stage time series and eco-hydro relationships. If the user intends to visualize statistical results spatially (GIS), data (and software) requirements increase significantly and include flow and stage time series, eco-hydro relationships, digital topography, a geo-referenced hydraulic model, and any other spatial data relevant to the ecosystem investigations.

**Eco-Hydro Relationships.** Central to EFM analyses are “functional relationships.” These relationships link characteristics of hydrologic and hydraulic time series (flow and stage) to elements of the ecosystem through combinations of four basic criteria – 1) season, 2) flow frequency, 3) duration, and 4) rate of stage recession – that determine the statistical analysis to be performed for each relationship. There is no limit to the number or genre of relationships that may be developed and the EFM user interface facilitates entry and inventory of criteria. During formulation of relationships, it is important for study teams to hypothesize about the effects that changes in flow would have on the ecosystem elements being characterized through each relationship.

**Use of Statistical Analyses.** After relationships are developed, the computational engine (managed by the interface) analyzes flow and stage time series for the specified criteria and produces a single flow value for each relationship. This process is repeated to assess each alternative flow regime and resulting values for without- and with-project conditions are compared to indicate the direction of change of ecosystem health for each relationship (in accordance with the hypotheses discussed above).

**Hydraulic Modeling.** Steady-state hydraulic modeling (flow held constant at a given point and routed through a river section) allows the statistical results (single flow values for each relationship) to be translated into water surface profiles. To date, HEC-RAS has been the hydraulic model of choice for EFM applications. If using a geo-referenced hydraulics model, the water surface profiles produced by HEC-RAS can then be translated into GIS coverages of inundated area, depth grid, and velocity grid by HEC-GeoRAS, which is a pre- and post-processor for HEC-RAS.

**Use of GIS in Restoration Projects.** GIS allows EFM users to display generated coverages (water depth, velocity, and inundated area) as well as other relevant spatial data (e.g., soils, vegetation, and land-use maps). The ability to assess results spatially is a strength of the EFM. GIS (and hydraulic modeling) improves EFM applications by: 1) helping project teams to visualize existing ecologic conditions and highlight promising restoration sites, 2) computing depth and velocity data that can be used as criteria to further define relationships, and 3) making it possible to assess multiple alternatives incrementally - through GIS, inundated areas for individual relationships can be compared and ranked as a measure of the relative enhancement (or decline) of that ecosystem element for any number of alternatives.

## MODEL USE

**Statistical Analyses.** A fundamental use of the EFM program is to execute statistical analyses of flow and stage time series in accordance with criteria specified by the user. All steps

in this process - entering criteria, executing statistical computations, and viewing results – are performed by the user via the model interface.

**The User Interface.** The interface consists of three tabs (Figures 1, 2, and 3). Users can switch from tab to tab at any time.

- *Properties tab.* This tab (Figure 1) contains information relevant to the project as a whole including project title, author, description, and the name and location of the input data file, which contains the flow and stage time series needed for statistical analyses.

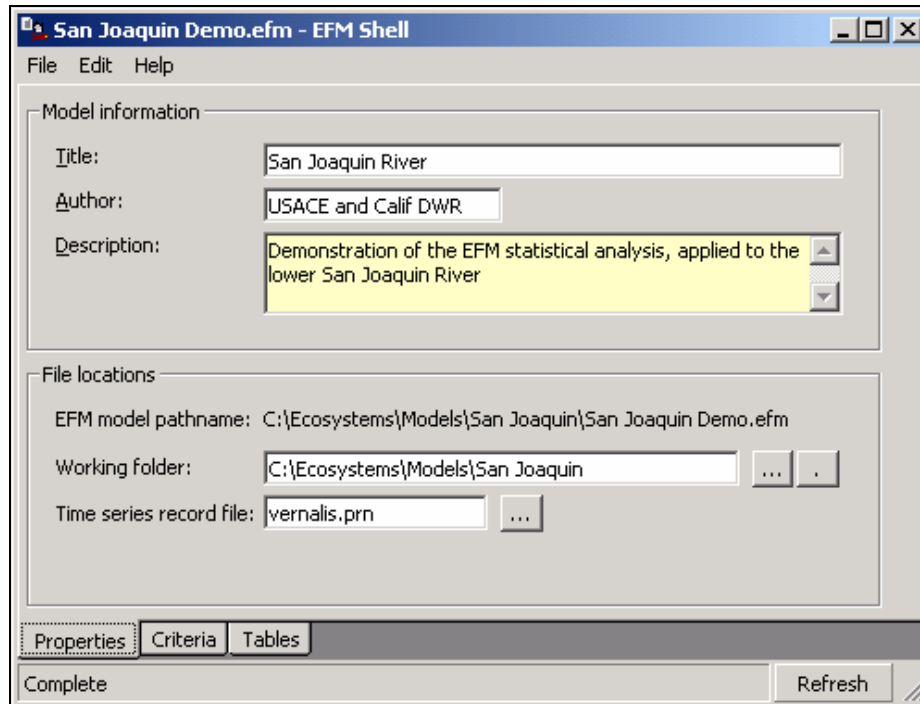


Figure 1. EFM Shell Properties tab

- *Criteria tab.* The primary purpose of this tab (Figure 2) is to allow users to enter criteria (in terms of season, flow frequency, duration, and rate of stage recession) that define the statistical analysis to be performed for each eco-hydro relationship. Users may also specify depth and velocity ranges of interest to the study team and the locations and names of relevant spatial data for any particular relationship, which will later be used in ArcGIS to guide the display and processing of spatial results.
- *Tables tab.* This tab (Figure 3) presents results of the statistical analyses. After entering or changing the statistical criteria of any relationship, the user must click the Refresh button to update the results table. To analyze an alternative flow regime, input a new set of flow and stage time series via the Properties tab (Figure 1) and click Refresh. The EFM will perform the statistical analyses and output results to the Tables tab (Figure 3). Results of the two flow regimes can be compared and, based on the hypotheses proposed during formulation of alternatives, used to determine the relative enhancement (or decline) of ecosystem aspects.

San Joaquin Demo.efm - EFM Shell

File Edit Help

Criterion name: Riparian IA-4b (Use Page Up and Page Down keys to navigate)

Description: Relative extent of wetland and riparian zones (10-yr)

**Statistical queries**

☒ Season  
From: 10/01 (m/d)  
to: 09/30 (m/d)

☐ Duration of inundation  
   days

☒ % chance exceedence  
10 % (10.00-yr)

☐ Rate of recession  
   feet per 7 days

☐ Criterion-defined year  
  

**Geographical queries**

☐ Velocity  
From    to    ft/sec

☐ Depth  
From    to    ft

**Map layers**

Other map layers:

☐ soils.shp ...

☐ vegetation.shp ...

☐ landuse.shp ...

☒ HEC-RAS and GeoRAS information:

Inundated area shapefile: fpw5yr.shp ...

Depth grid coverage: dgw5yr ...

Velocity grid coverage: vqv5yr ...

Shear stress file: shear5yr.txt ...

Properties Criteria Tables

Complete Refresh

Figure 2. EFM Shell Criteria tab

San Joaquin Demo.efm - EFM Shell

File Edit Help

Refreshed at: 09/12/2002 08:12

Summary Table		
Based on the entire length of streamflow record		
Criterion Name	Stage, ft	Flow, cfs
Riparian IA-2 - Depth of water table	2.59	1458
Riparian IA-3a - Flood events suitable for plant establishment (Cottonwoods)	4.71	2924
Riparian IA-4a - Relative extent of wetland and riparian zones (5-yr)	24.35	33340

Properties Criteria Tables

Complete Refresh

Figure 3. EFM Shell Tables tab

**Hydraulic Analyses.** Hydraulic models are used to translate the statistical results to water surface profiles, which can be further translated to GIS coverages. To date, HEC-RAS and GeoRAS have been the hydraulic modeling tools used during EFM applications.

HEC-RAS is a software system that performs a variety of hydraulic analyses, including computations of steady-flow water surface profiles (USACE 2001). This steady-state modeling is used in EFM applications to translate statistical results (single pairs of flow and stage values) to water surface profiles. GeoRAS is a pre- and post-processor for HEC-RAS (USACE 2000). In pre-processor mode, GeoRAS allows users to define cross sections based on digital topography of the study area. These cross sections are input to HEC-RAS and give shape to the virtual channel used during river routing simulations. For each unique flow (statistical result), HEC-RAS will produce a corresponding water surface profile. GeoRAS can then translate these profiles to GIS coverages of water depth, velocity, and inundated area (Figure 4).

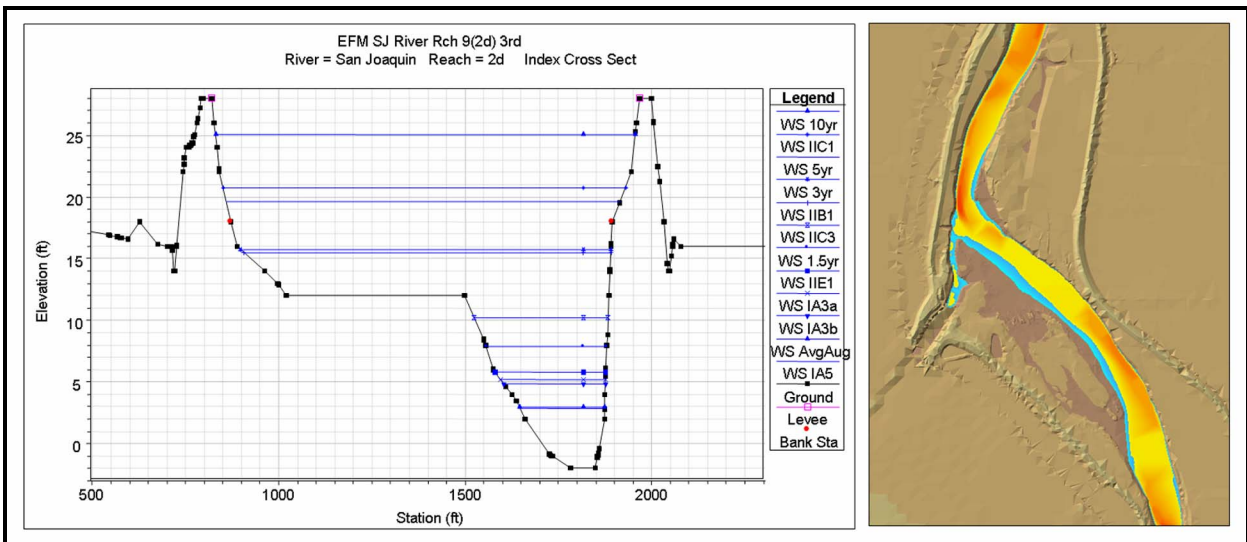


Figure 4. *HEC-RAS output in the form of steady-state water surface profiles (left) and the GeoRAS translation of profiles to GIS coverages (right)*

The EFM interface provides text fields for the names and pathnames of the GIS coverages of water depth, velocity, and inundated area produced by GeoRAS. The ArcGIS application will use these references to activate these coverages when the corresponding eco-hydro relationship is selected.

**Spatial Analyses.** Spatial functions of the EFM are being programmed as a “plug-in” for ArcGIS software (Figure 5). The purpose of the EFM plug-in is to bundle a few commonly used functions into an easy-to-use package for EFM users who are not GIS specialists. To employ the plug-in, users must have ArcGIS 8.0+ (or ArcView 8.0+) with the Spatial Analyst extension.

Currently, spatial processes are limited to the generation of new coverages with specific ranges of depth or velocity (ranges specified in the EFM interface; coverages generated via the EFM plug-in). For example, if you wanted to assess an EFM relationship for a fish species that spawns in the springtime and requires shallow-water habitat, statistical results could be

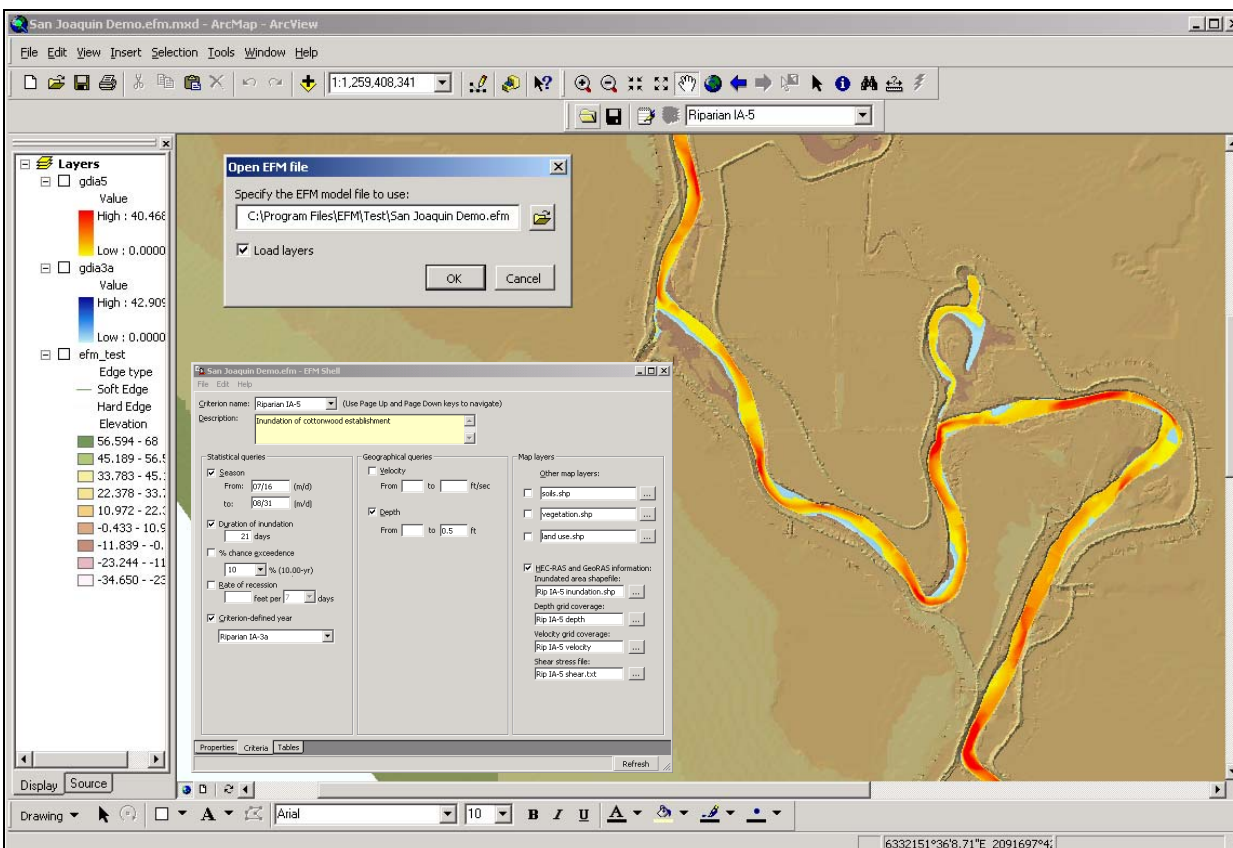


Figure 5. EFM Spatial Processor

computed by the EFM interface, HEC-RAS and GeoRAS could translate statistical results to a depth grid of inundated area, and, finally, the plug-in could delineate which portions of that inundated area meet the depth range suitable for fish spawning.

In the future, HEC plans to expand the EFM's spatial capabilities by bundling more functions, including area computations and intersections of multiple coverages. However, these capabilities and others are already available through software in the ArcGIS suite.

## CASE STUDY

This section focuses on the use of relationships in EFM applications and interpretation of results. Materials presented herein were developed in support of the Sacramento and San Joaquin River Basins Comprehensive Study as part of the pilot application of the EFM, which investigated a reach of the lower San Joaquin River near Vernalis, California.

**Study Area.** The San Joaquin study area is roughly 12.5 river miles in length. Waters in this stretch flow to the north. There are no significant tributaries or diversions within this area and there is a USGS stream gauge located near Vernalis (close to the southern (upstream) end of the study area) that has been measuring daily flow and stage values since 1923. There are roughly



29 upstream reservoirs (larger than 10,000 ac-ft). Figure 6 shows an aerial photo and GIS layout of a portion of the study area.

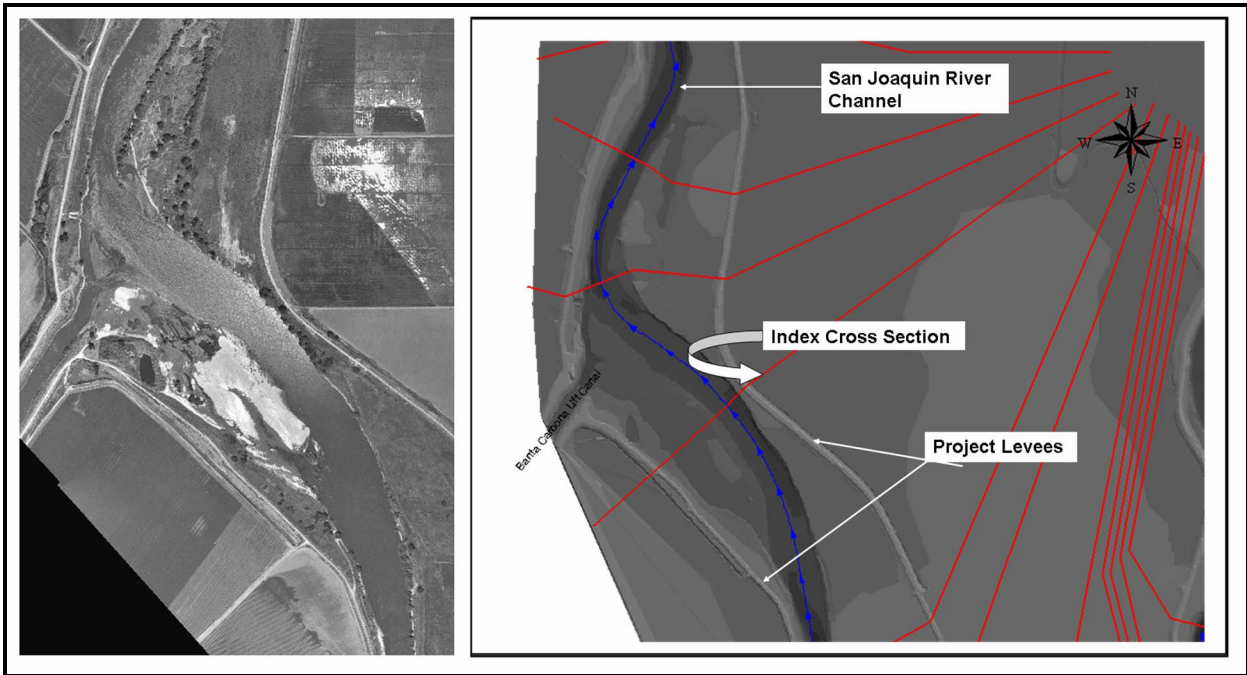


Figure 6. *Aerial photo and GIS layout of a northern portion (approximately 1 river mile in length) of the San Joaquin River study area. Channel cross sections visible in the GIS layout are input to HEC-RAS and define channel topography during flow routing simulations*

This particular EFM application was fortunate in that a geo-referenced HEC-RAS hydraulic model had already been constructed for the entire study area. The index cross section (Figure 6) was chosen from the set of cross sections used in HEC-RAS modeling as representative of the entire 12.5-river-mile study area. Selection was based on visual investigation of channel topography throughout the study area.

**Hydrologic Data.** Daily flow records from the San Joaquin River near Vernalis gauge were used directly. As the index cross section was not located at the gauge site, average daily stages were computed based on the gauged flows and the topography at the index cross section.

**Eco-Hydro Relationships.** The pilot application of the EFM used 15 relationships to investigate a range of ecosystem elements, including fish spawning, fish rearing, fish stranding, recruitment of large woody debris, channel migration, riparian forest regeneration, and many others. Relationships were prepared by a team of engineers, biologists, and environmental planners. Expert knowledge and scientific literature were both used during development (Jones and Stokes 2000). The rest of this section details one of these relationships (floodplain fish spawning) to demonstrate the complete EFM process of statistical analysis, hydraulic modeling, and GIS display and analysis.

**Floodplain Spawning Habitat Relationship with Alternatives Analysis.** Sacramento splittail is a threatened species of minnow indigenous only to the Sacramento and San Joaquin

River Basins. Splittail populations have declined (in magnitude and range) as dams and diversions cut access to upstream river stretches and as floodplain areas, critical to splittail spawning, were channelized and transitioned to agricultural lands.

- *Relationship for Floodplain Habitat.* Splittail spawn in shallow vegetated floodplain areas between February and May. Eggs incubate approximately 21 to 28 days before hatching. Splittail reach sexual maturity in their first or second year and have a lifespan of approximately 5 years. Spawning habitat must be available frequently, possibly 50 to 25 percent of the time (2- to 4-year return period), to sustain populations. Increased flows within the spawning period are likely to create added habitat and, therefore, are anticipated to enhance this aspect of the ecosystem.
- *Statistical Criteria.* The floodplain spawning relationship was scripted with: 1) a season of February 1 through May 31, 2) a 21-day duration for incubation, 3) a 25-percent exceedance (4-year) frequency (Figure 7).

The screenshot shows the 'San Joaquin Demo.efm - EFM Shell' window. The 'Criterion name' is 'Floodplain IIB-1' and the 'Description' is 'Floodplain spawning habitat'. The 'Statistical queries' section includes: 'Season' (From: 02/01 to: 05/31), 'Duration of inundation' (21 days), '% chance exceedance' (25 % (4.00-yr) exceedance), 'Rate of recession' (7 feet per 7 days), and 'Criterion-defined year'. The 'Geographical queries' section includes: 'Velocity' (From 0 to 1 ft/sec) and 'Depth' (From 0 to 2 ft). The 'Map layers' section includes: 'Other map layers' (three empty fields), 'HEC-RAS and GeoRAS information' (checked), 'Inundated area shapefile' (fpib1.shp), 'Depth grid coverage' (gdib1), 'Velocity grid coverage' (vgib1), and 'Shear stress file' (Shear-iib1.txt). The 'Properties' tab is selected, and the 'Complete' button is visible at the bottom left.

Figure 7. Floodplain spawning habitat relationship

- *Alternatives Analysis and Discussion of Floodplain Spawning Habitat.* GIS results of the floodplain spawning relationship were overlaid with the 67-percent exceedance (1.5-year) frequency to delineate channel and floodplain habitats. Time series reflecting a reservoir reoperation alternative (with-project conditions) were prepared and input to the EFM. Based on the same criteria set, the magnitude of the statistical results (flow-stage pair) for the floodplain spawning relationship was increased through reoperation. GIS coverages were prepared and plotted with visuals of existing (without-project) conditions. Results indicate a positive ecological response



for floodplain spawning under alternative conditions (Figure 8). Again, users are cautioned against thinking of EFM results in terms of habitat maps; results are appropriately used as indicators of the direction of change of ecosystem health for individual relationships.

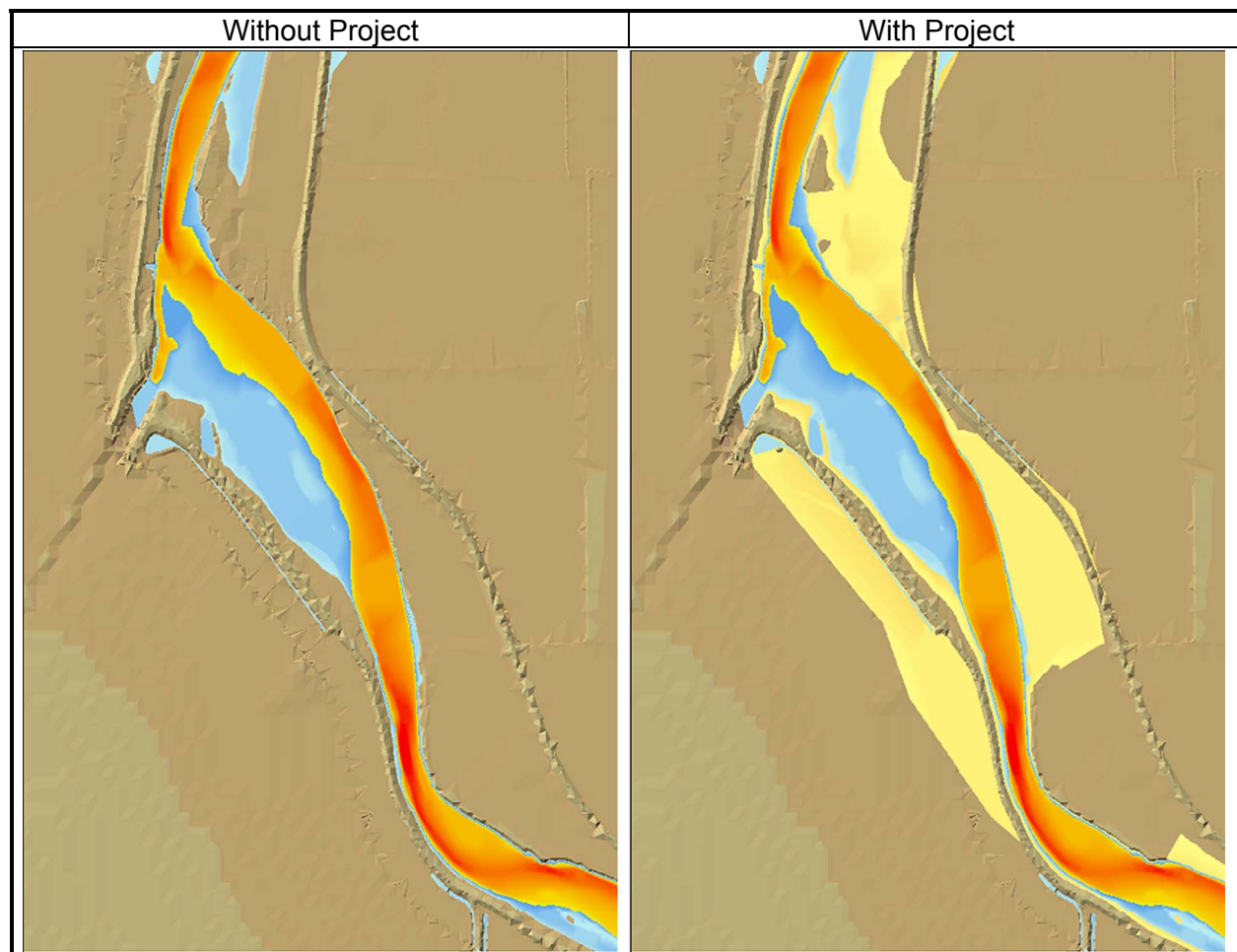


Figure 8. GIS display of floodplain habitat for splittail spawning under without- and with-project conditions. This alternative focused on the use of reservoir releases to mimic a more natural flow regime

**SUMMARY:** The EFM is a planning tool that analyzes ecosystem response to changes in flow regime. While, to date, it has been applied only to three restoration projects in the Central Valley of California, the EFM is applicable to a wide range of ecotypes and Corps projects.

The EFM is capable of analyzing ecosystem response to any number or combination of factors that affect river flows, including reservoir reoperation, channel alteration, changes in water use, etc. The software is actually best suited to assess ecosystem processes (e.g., habitat trends for any number of species, recruitment, mortality, etc.) in comparative settings involving alternative flow regimes.

This flexibility in use makes the EFM a promising tool for 1) investigating cumulative impacts that tend to plague watershed studies – the EFM’s ability to act in a complementary role for reservoir simulation and river hydraulics models makes technical support for projects more holistic, 2) improving knowledge transfer between restoration projects – learning from others is a fundamental way to avoid repeated mistakes; the EFM can be used to assess ecosystems ranging from salmon runs in the Pacific Northwest to floodplain vegetation in the Southeast, a flexibility which promotes understanding because diverse projects share a common tool, and 3) communicating ecosystem dynamics – this is really strengthened by the use of GIS, which allows users to view and display data generated by hydraulic analyses (as well as those imported from existing sources).

A beta version of the software with user’s manual (USACE 2003) is available. For more information regarding the EFM, please contact John Hickey, HEC.

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## REFERENCES

- Jones and Stokes. (2000). *Final functional relationships for the Ecosystem Functions Model*, Sacramento and San Joaquin River Basins Comprehensive Study, Sacramento, CA.
- U.S. Army Corps of Engineers (USACE). (2000). *HEC-GeoRAS: An extension for support of HEC-RAS using ArcView, User’s Manual*, CPD-76, Hydrologic Engineering Center, Davis, CA.
- U.S. Army Corps of Engineers (USACE). (2001). *HEC-RAS: River Analysis System user’s manual*, CPD-68, Hydrologic Engineering Center, Davis, CA.
- U.S. Army Corps of Engineers (USACE). (2003). *HEC-EFM: Ecosystem Functions Model user’s manual*, Hydrologic Engineering Center, Davis, CA.

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